Low-Cost Networking for Dynamic Window Systems

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Abstract

A low-cost building communications network is needed that would allow individual window and lighting loads to be controlled from an existing enterprise LAN network. This building communications network concept, which we term IBECS™ (Integrated Building Environmental Communications System), would enable both occupant-based and building-wide control of individual window, lighting, and sensor devices. IBECS can reduce the cost of systemic control because it allows a drastic cost reduction in per point networking costs. This kind of effort is needed to encourage the control industry to make the commitment to build this technology and to demonstrate to prospective customers that this breakthrough approach to more comprehensive systemic control will provide them with high-quality, convenient control while saving them money.

The development and demonstration of network interfaces to DC- and AC-motorized shades and to an electrochromic window are described. The network interfaces enable one to control and monitor the condition of these fenestration appliances from a variety of sources, including a user's personal computer. By creating a functional specification for an IBECS network interface and testing a prototype, the ability to construct such an interface was demonstrated and the cost-effective price per point better understood. The network interfaces were demonstrated to be reliable in a full-scale test of three DC-motorized Venetian blinds in an open-plan office over two years and in limited bench-scale tests of an electrochromic window.

Keywords: Building energy-efficiency, electrochromic windows, motorized roller shades, motorized Venetian blinds, controls, networking.

1. Introduction

Over the last twenty-five years, the US Department of Energy (DOE) in partnership with the window industry has revolutionized the window products available to consumers and specifiers. Low-E coated glass, unknown in the 1970s, is now used in over 40% of all residential windows sold in the US. Spectrally selective glazings are beginning to penetrate the commercial sector as well. Despite the impressive savings, windows still make a large contribution to the US annual building energy consumption of $265B in 2000 [1]. Further penetration of existing technologies will increase energy savings but will begin to have diminishing returns. In 2002, DOE worked with members of the window industry to create a roadmap that defined the technologies and tools that will be needed to create and sell the next generation of windows in the 21st century [2]. Window industry executives identified a new generation of dynamic, responsive "Smart Windows" as the number one top priority. The emerging concept of the window will be

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more as a multi-functional "appliance-in-the-wall" rather than simply a static piece of coated glass. These façade systems include smart windows and shading systems such as motorized shades, switchable electrochromic or gasochromic window coatings, and double-envelope window-wall systems that have variable optical and thermal properties that can be changed in response to climate, occupant preferences and building system requirements. By actively managing lighting and cooling, "smart windows" could reduce peak electric loads by 20-30% in many commercial buildings and increase daylighting benefits throughout the US, as well as improve comfort and potentially enhance productivity in our homes and offices. These technologies can provide maximum flexibility in aggressively managing demand and energy use in buildings in the emerging deregulated utility environment and can move the building community towards a goal of producing advanced buildings with minimal impact on the nation's energy resources. Customer choice and options will be further enhanced if they have the flexibility to dynamically control envelope-driven cooling loads and lighting loads.

There are significant R&D programs world-wide that are working toward technological solutions for dynamic window-lighting systems. The International Energy Agency Task 31: "Daylighting Buildings in the 21st Century" is investigating user acceptance of automated shading and daylighting systems [3] through a series of full-scale field and laboratory studies. Fuzzy logic and neural network control algorithms have been applied and demonstrated with an automated Venetian blind using European Installation Bus (EIB) Association Standards (http://www.konnex-knx.com/) at the Swiss institute, LESO-EPFL [4]. Philips Lighting BV and the Netherlands Organization for Applied Scientific Research (TNO-TUE) are conducting a user acceptance study of electrochromic windows as part of a larger EU study on chromogenic facades [5].

There has also been increased interest in motorized shading systems due to the recent architectural trend towards all-glass facades. These highly transparent facades typically specify floor-to-ceiling clear or low-iron clear glass to achieve a dematerialization of the façade. Motorized exterior or interior shading systems are frequently used to control the direct sun and glare that occurs with these designs. In high-profile buildings such as the debis Headquarters building in Berlin, the Environmental Building in Garston, UK, and RWE AG Headquarters in Essen, Germany, motorized louvers or blinds have been installed between a double-layer glazed wall to work as part of a heat extraction system [6]. Automated shade systems have also been installed in the Gregory Bateson Building in Sacramento, California, the Pacific Bell Center in San Ramon, California, and the San Francisco Main Public Library over the past several decades.

In the US, manufacturers have implemented stand-alone building-wide control of motorized shades using a variety of control solutions including proprietary RS232 and RS485 systems, and open protocol systems such as Echelon LonWorks. Most commercial motorized shading systems are not integrated with other building systems, although Lutron Electronics Inc. and Vimco, a subsidiary of Lutron, have developed a low voltage and radio frequency whole-home control system that includes both lighting and motorized roller shades. Somfy Systems Inc. offers a number of integrated control products developed for standard bus solutions: SCHNEIDER Group BatiBUS, EIB, and Echelon LonWorks. Other manufacturers, such as MechoShade Systems, can integrate proprietary individual control solutions with larger Energy Management System (EMS) products via gateways. Shades are most commonly group controlled via a series of relays; the more devices that can be put on a relay, the lower the capital cost for such a solution. Each group can be assigned a globally unique address and be controlled via the network through a user control interface or the central, master control system.

To attain the goal of complete flexibility in layout, reconfiguration, and operations, *individual* control and networking of interoperable devices (i.e., *each* motor, ballast, sensor, or window) is preferred. Integration of shading systems with the lighting system and even the infrastructure of the EMS, which is already in many buildings for the purpose of controlling the HVAC system, is desirable to realize the full energy-savings potential identified above. Commissioning, maintenance, and diagnostics are also facilitated by networking individual devices and sensors and by placing the control and diagnostic software customarily found on dedicated circuits upstream of the device. The downside of individual device networking is cost. Interoperable building equipment systems using the networking control solutions noted above (e.g., LonWorks) results in high costs per individual control point ($15-30/ control point) which, for lighting and window systems, competes with the total cost of the device itself. If the price per point can be reduced, then the challenge of doing systemic control can be accomplished.

A low-cost building communications network is needed that would allow individual window and lighting loads to be controlled from an existing enterprise LAN network. LBNL is developing a building communications network concept, which we term IBECS™ (Integrated Building Environmental

Communications System), that would enable both occupant-based and building-wide control of individual window, lighting, and sensor devices. IBECS can reduce the cost of systemic control because it allows a drastic cost reduction in per point networking costs and for some devices eliminates separate controllers per control zone.

This research was conducted as part of the High Performance Commercial Building Systems program under the California Energy Commission's buildings-related energy efficiency research, development and demonstration (RD&D) "programmatic" effort of the Public Interest Energy Research (PIER) Program [7]. The overall task for Element 3: Lighting, Envelope, and Daylighting of this program was to develop network interfaces that would enable one to control and monitor the condition of an overhead fluorescent light or fenestration appliance from a variety of sources, including a user's personal computer. By creating a functional specification for an IBECS network interface and testing a prototype, the ability to construct such an interface would be demonstrated and the cost-effective price per point better understood. This kind of effort is needed to encourage the control industry to make the commitment to build this technology and to demonstrate to prospective customers that this breakthrough approach to more comprehensive systemic control will provide them with high-quality, convenient control while saving them money.

In this paper, we describe our efforts to design, build and test cost-effective IBECS network interfaces to motorized shading and switchable window systems. Note that our development work focused on the direct interface to the shading or window device, or the direct **point of use** to the shade or window. This low-level interface can be married to any combination of upper-level hardware and software solutions. The basic design of the IBECS concept is explained. A detailed description of a network interface to a DC motorized shade is given. A brief description of a network interface designed for an AC motorized shade and an electrochromic window is also given. A discussion of the network interface designs outlines potential use in typical commercial office buildings and looks at the costs associated with such a system.
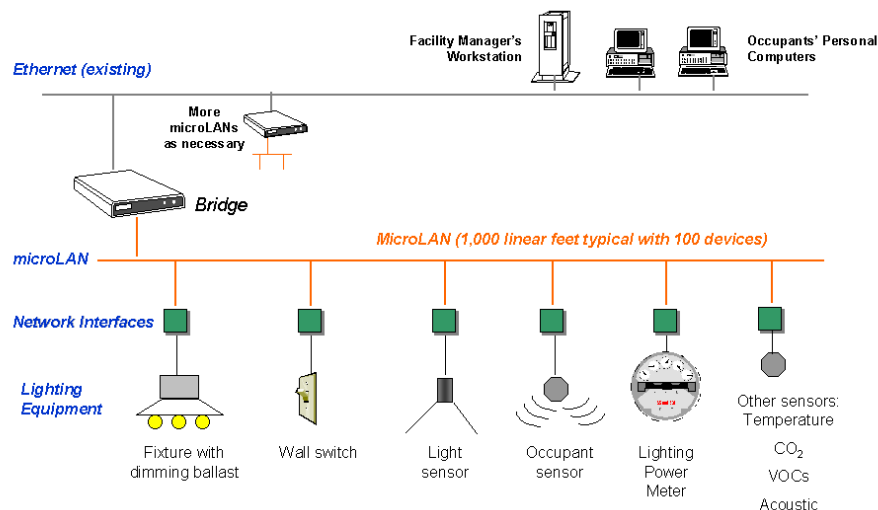

Fig. 1. Diagram of Integrated Building Environmental Communications System (IBECS).

2. Background

Figure 1 illustrates a more comprehensive view of the entire IBECS concept as applied to the operation of electric lighting and operable window systems. In the diagram, it is assumed that IBECS will be installed in a building that already has an in-place TCP/IP network for integrating the enterprise's computer network. In this concept, the MicroLAN bridge is an intelligent device that couples the existing Ethernet network to the new MicroLAN – a simple, low-cost field bus that networks together various devices and sensors for that building zone. The MicroLAN bridge, which can serve up to 200 network interface devices, must contain considerable computational horsepower since it needs to reliably coordinate

communications between many networked devices and must also be capable of serving as a robust bridge to Ethernet. However, the network interface requires little embedded intelligence merely to operate a device and provide signal acknowledgment. This means that the network interfaces can be produced using inexpensive microchips. In IBECS, we are using the microchips from Dallas Semiconductor/ Maxim. A more detailed explanation of this concept can be found in [8].

This research also builds on prior work where a DC-motorized Venetian blind and lighting system was designed, built, and integrated with a dimmable fluorescent lighting system [9]. In this study, control was accomplished by a standard 0-10 V analog signal. The system was refined, tested, and monitored over several years in two full-scale unoccupied offices. Energy performance and user acceptance and satisfaction were evaluated for a non-retractable Venetian blind. A second series of studies was also conducted on an automated retractable and tilting AC-motorized Venetian blind but these results were not published. The existing controller relied on digital control and actuated using an analog voltage. In order to interface with the IBECS system, this controller was redesigned.
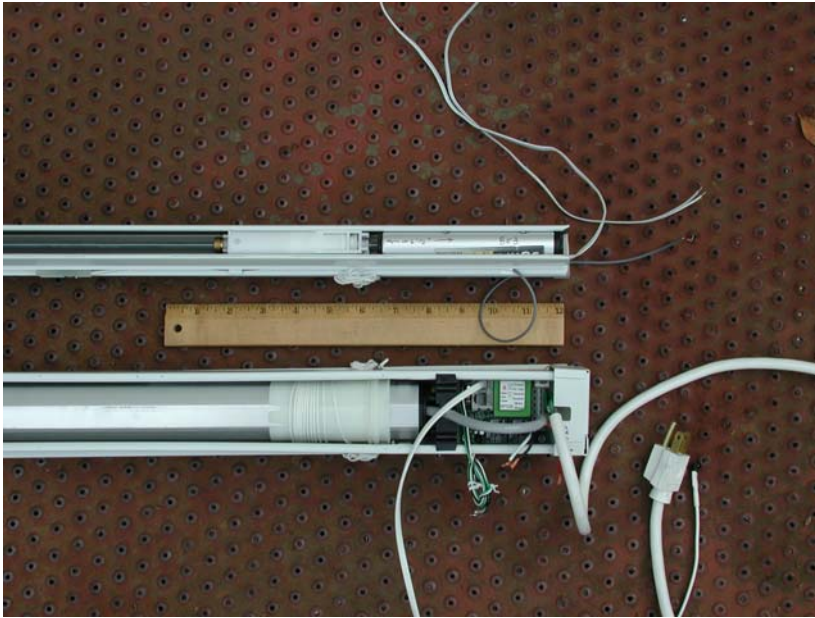

Fig. 2. Photograph of DC (top) and AC motor (bottom) in head rail of motorized Venetian blinds.

3. Motorized Shade Network Interface

There are many types of shading systems: interior or exterior shades, horizontal or vertical shades, roller shades, Venetian blinds (typically 1.27-7.62 cm, 0.5-3.0 in wide), louvers (~0.07-1 m, ~3-36 in wide), blind or louver systems with string ladders, tape ladders, or metal ladders for tilt angle adjustment and raise and lower function. While many types of shades can reduce solar heat gains and result in increased energy-efficiency compared to an unshaded window, we focused on developing a network interface to a common interior horizontal Venetian blind with string ladders and assumed that the shades could be polled and potentially activated as frequently as every 1-5 min.

A satisfactory solution for controlling this type of shade should have the following capabilities:
- tilt the slats or louvers rapidly and smoothly to a specified angle over the full tilt angle range,
- raise and lower the shade rapidly and smoothly to a specified height above the floor, and
- achieve movement with minimal noise.

Two types of motors are used predominantly in commercially-available shading systems: AC and DC tubular motors (Fig. 2). The motors are typically mounted in the head rail of the shade and sold as a unit (bottom-up retraction of Venetian blinds is also featured by some product lines, which is useful for daylighting applications). A 110 V or 277 V AC motor is typically used in applications where raising and

lowering of a large heavy shade (11-140+ kg (25-300+ lb)) is required. Tilting requires much less power than raising a blind, but the latter function determines the size of the motor needed for installation in the blind header. For the application we were considering, AC motors proved to be less desireable than low-voltage DC motors because:

- moderating the power and speed of the AC motor is difficult for both tilt and lift functions and the speed control circuitry is expensive and not readily available;
- the AC motor is mechanically larger and requires a larger (5x5 cm, 2x2 in) header; and
- the lethal voltage of the AC motor increases wiring expense,
- the noise level is typically greater than DC motors.

At full power, both the AC and DC motor systems can rapidly perform tilting at a rate that can disturb occupants: e.g., full ~180˚ change in tilt within 1-2 s. This may be satisfactory for occasional daily adjustments, but this would not be acceptable for automated control where blinds may be activated several times per hour and fine adjustments to the tilt angle are required. Rapid motion also makes it difficult to accurately determine slat angle during closed loop operation. When changing the slat tilt, the speed must be adjusted for a slow rate of change to avoid visually distracting the occupant and to avoid jerky movements. For a DC motor, this can be done by halving the applied voltage and pulsing it at a low frequency with a variable duty cycle. Full speed operation, required when raising and lowering the blind, can be performed by applying the rated 24 V. Decreasing the speed of operation for an AC motor with very inexpensive controls requires pulsing the full 120 V power. This significantly increases motor noise. Gearing down an AC motor to achieve small tilt movements is also not feasible, since the gears do not have enough resolution.

A detailed study was performed on DC motors since they best met the requirements for tilting the blind. The designs for a network interface to an AC motorized shade and electrochromic window are presented following the discussion of the DC motor interface.

3.1. Network interface to a DC motorized Venetian blind

The minimum requirements for automated blind operation through the IBECS network were:

- activate the motor at full power for raising and lowering operation;
- determine when this operation is completed;
- activate the motor at a reduced power level when tilting the slats; and
- measure the slat tilt angle for closed-loop control of the tilt function.

These requirements were met by building and assembling a number of components as described below.

3.1.1. Blind Motor Control Circuitry

To assure proper operation of the blind in reaching the desired position without hesitation, hunting or overshoot, blind motor control circuitry was designed to operate in a local, closed-loop mode independent of the 1-Wire network. Doing so enabled us to precisely control the timing of how quickly and smoothly the Venetian blind slats were tilted. An algorithm could be designed around a global, central control system. This would reduce the complexity of the interface control at the blind and reduce costs. Power level and motor direction could be set centrally as well as activation. During tilting, the slat angle could be measured over the network and the motor stopped at the desired tilt.

This approach was not developed because of the inherent nature of the broad, low cost IBECS network. It is a relatively low speed communication conduit (about 9600 baud in "standard mode") with the likelihood of having dozens of devices listening and talking on this simple "1-Wire" channel. The response time of the network may not be satisfactory for real-time control. For example, to operate a switch with IBECS one must consider the time it takes to open or release a switch. For closed-loop control functions that are critically time-sensitive (on the order of milliseconds), control must be implemented independent and downstream of the network. The IBECS network is best used to send a command for a device to change its state or transmit data back for monitoring purposes. The details of how a complex device like a Venetian blind is to change to this new state is best done at the local level.
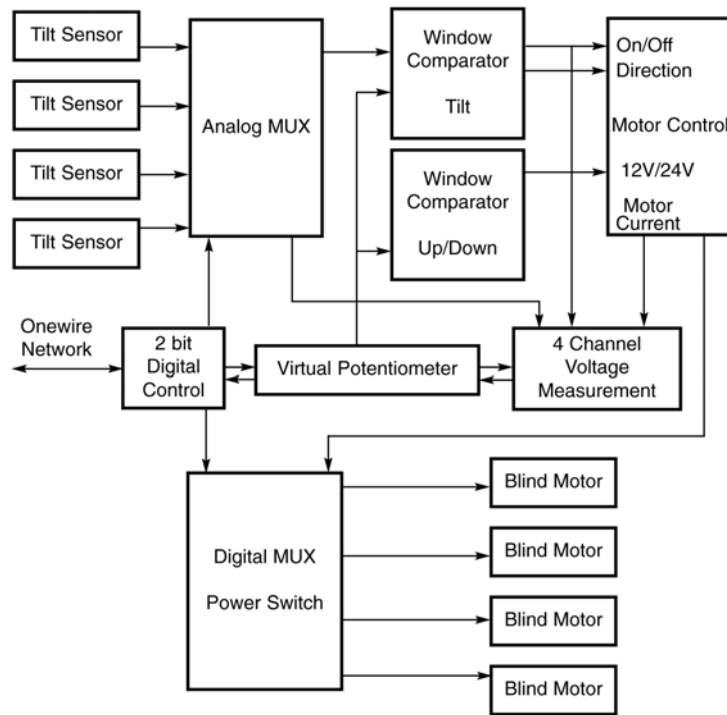
Fig. 3. Block circuit diagram of the network interface and multiplexing circuit for a DC-motorized Venetian blind.

3.1.2. IBECS Network Interface

The IBECS network interface was accomplished with two Dallas Semiconductor/ Maxim integrated circuits (IC)[1]: DS2890, a virtual potentiometer IC, and DS2450, a 4 channel voltage measuring IC (Fig. 3). The former delivers a command from the IBECS network to the blind control circuitry in the form of a control voltage. The latter's voltage measurements monitor the blind's:

- tilt angle through a low-g accelerometer chip mounted on one of the blind slats,
- tilt motion status by a digital high/low signal from the voltage window comparator, and
- motor operation by measuring the current flowing through the motor.

A tilt sensor was constructed around the accelerometer IC, ADXL05, from Analog Devices Inc.[2] It was soldered onto an approximately 1.5 cm square circuit board with a few auxiliary components. This board was mounted on the blind's top slat, to minimize cable length changes when the blinds are raised and lowered. When powered by a 5 V supply, the output signal was 2.5 V when horizontal, varying by ± 0.5 V when tilted $\sim \pm 90°$ from the horizontal.

In applying the DS2890, we found it necessary to turn on the digital potentiometer's charge pump. The charge pump requires an external power source (typically 12 V DC) which is connected to one pin (Vcc X) on the digital pot. Applying external power slightly increases the complexity of the network wiring since an additional conductor must be added to the network cable.

Power control of the blind motor was through a solid-state MOSFET AC relay, PVG612.[3] Using a solid state relay allowed the function of switching the blind motor on and off to be combined with pulsing the power to modulate the rate of blind motion.

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[1] Technical specifications can be found at http://pdfserv.maxim-ic.com/arpdf/DS2890.pdf and http://pdfserv.maxim-ic.com/arpdf/D2450.pdf. Note the selection of this company's hardware to construct the interface does not imply that there are not other companies that have similar products and capabilities.

[2] Recently, the ADXL05 has been replaced with the improved ADXL105 or ADXL202 IC. Technical specifications can be found at http://www.analog.com/.

[3] Technical specifications can be found at:
http://ec.irf.com/v6/en/US/adirect/ir?cmd=catSearchFrame&domSendTo=byID&domProductQueryName=PVG612.

The voltage control signal from the virtual potentiometer was compared to the actual tilt sensor signal by a window comparator, LTC1042. The comparator also has a deadband input adjustment to prevent excess hunting. When the tilt signal was outside the acceptable window, pulsed DC 12 V power is applied to the motor by an ubiquitous 555 IC oscillator circuit. A second window comparator is utilized to determine when the control signal is outside the tilt signal limits. When outside the limits, the control signal was interpreted as a command to raise or lower the blinds. This second comparator switched the power to 24 V DC and defeated the oscillator so that uninterrupted power was delivered to the blind motor. Note that for raise and lower functions, the particular blind motor we used incorporates automatic limit stopping to prevent motor burnout when the Venetian blind has been fully retracted or extended. The status of the raising and lowering operations is determined by monitoring the current flowing through the motor (i.e., when motion is complete).

Partial extension of the blind is more difficult to accomplish automatically and was not implemented in the scope of this project. This would involve either a timing function on the motor (commissioned for a particular window) or a sensor to determine the vertical position of the Venetian blind. DC motor speed is affected by the distance of the line to the power source transformer. Therefore, DC motors move at different rates. DC motors can also use "encoders" to get the correct alignment of the shades. The current implementation requires that the user manually set the vertical height of the blind; that is, lining up the bottom rail of side-by-side blinds.
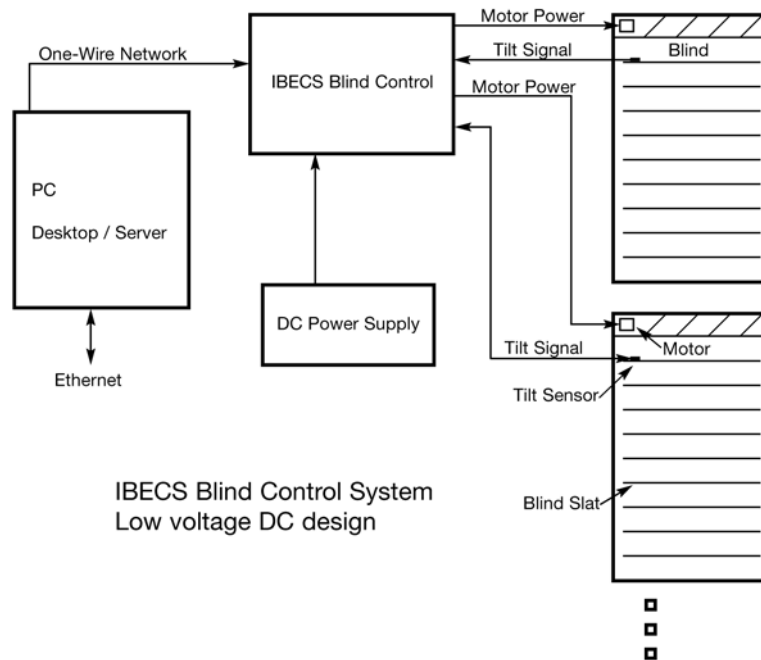

Fig. 4. Wiring diagram for multiplexed Venetian blinds (up to 8 or 16 blinds)

3.1.3. Expansion

The blind motor control system, while able to operate independent of the IBECS network after a command is received, is relatively complex. Since a motorized blind is inherently a stable device when unpowered, multiplexing the blind motor control circuitry to operate a series of blinds through digital addressing over the 1-Wire network is an economical approach to control. One motor control circuit could be used to operate numerous blinds in a section of a building without compromising individual blind control (Fig. 4 and 5). While this required that blinds be adjusted sequentially (if the user wanted to activate a group of blinds simultaneously), this was not judged a serious limitation because:

- Simultaneous operation of a number of blinds increases the likelihood of disturbing occupants.

- Simultaneous operation requires a power supply be sized for the worse case of simultaneous operation. This could result in needing a 10 amp or more 24 V DC supply for a dozen blinds, not a trivial expense or an energy-efficient solution.
- Tilt speed can be adjusted so as to not require excessive time when a series of blinds are moved in sequence.
- While raising and lowering a blind does take a significant time, this operation is not performed often.

To demonstrate the concept of multiplexing, the circuit in Fig. 3 was designed. IBECS network interface was through a DS2407 IC, a two bit digital I/O chip that we utilized as output only. We used these 2 bits to address an analog multiplexer (MUX08) that switched which tilt sensor was read and a digital multiplexer, 74LS138 which determined which power relay was closed for motor activation.

Each IC (and therefore blind motor) has a unique networking address that is automatically commissioned via the 1-Wire network. The circuit interfaces to the network with a 1-Wire screw-on connection.

Fig. 5. Photograph of network interface and multiplexing circuit (left) and DC power supply (right).

3.1.4. Blinds

To demonstrate the control system, three white, aluminum slat, Venetian blinds were mounted on west-facing windows in an open plan office in Building 90-3111 at the Lawrence Berkeley National Laboratory (Fig. 6). Each blind was 120 cm wide by 183 cm high with 2.54 cm wide slats (47x72x1 in). Motorization was done with Somfy 24 V DC tubular motors, Model LV25.[4] This compact motor fit in the 2.54 cm by 2.54 cm (1x1 in) headrail. The Somfy mechanism performs both tilt and lift functions with a single motor controlled only by its pair of power leads. These mechanisms have integral limits for raising and lowering the blinds but do not supply feedback as to the status of the motor or the tilt angle of the slats.

In earlier work, a cheaper motor was used to demonstrate the concept of automation. Controllers were designed to step the motor to achiever quieter, smoother tilt angle motion. The Somfy motor drive is more expensive than other competing motors, but it makes less noise when actuated quickly. By slowing the rate of the Somfy motor, motor noise was increased slightly but the noise level still remained within the ambient level of a typical office environment.

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[4] For technical specifications, see: http://pro.somfy.com/pro_eng/mot/mot100.shtml#f_int.
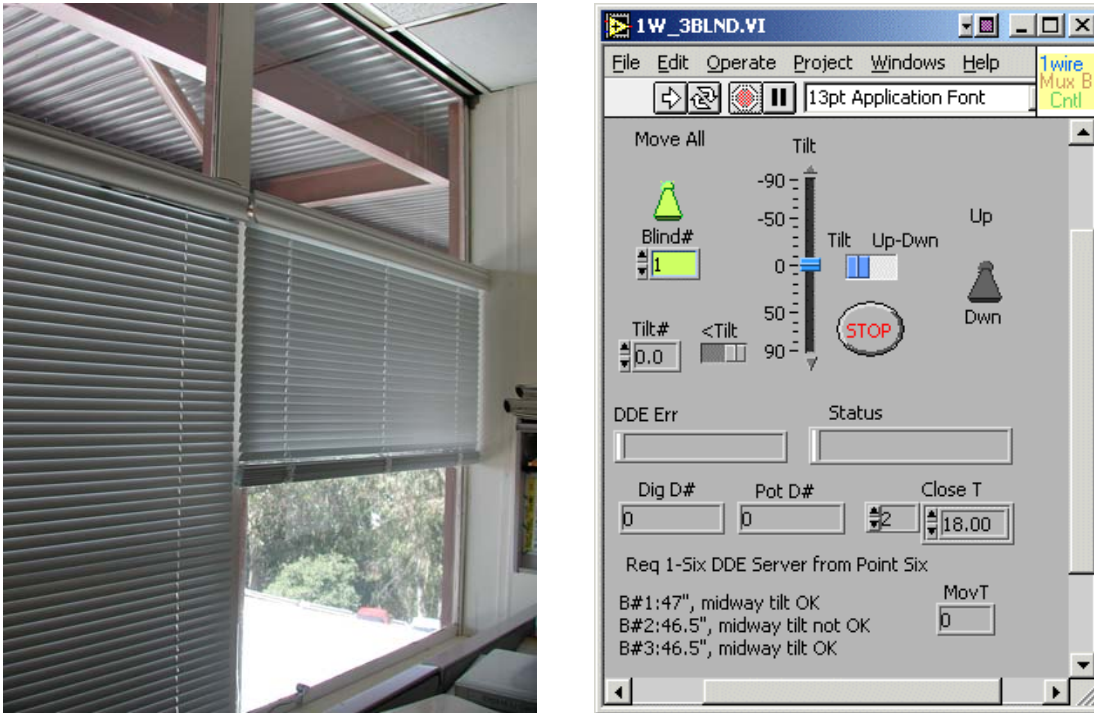
Fig. 6. Left: Photograph of the installed Venetian blind system at LBNL. The right-hand blind is shown partially retracted with the blades at 0˚ (horizontal). The center blind is fully extended but the blade angle is tilted 20˚ from horizontal. Right: Screen capture of the LabView "virtual instrument" control panel used to control the operation of the IBECS-controlled Venetian blinds.

3.1.5. User Interface

The three blinds were connected to a multiplexed control system with a network interface so they could be individually controlled. A low-voltage CAT-5 cable wire was used to connect all network interfaces, forming the IBECS microLAN. This microLAN was terminated with a RS232 microLAN bridge near the occupant's personal computer so that the occupant could control the Venetian blinds.

The IBECS network requires an interface or "bridge" to communicate through the common communication ports available on computers. For control through a single PC, simple bridges (also known as port adapters) are available that enable bidirectional data flow between a PC's serial port and the IBECS network. An HA-3 adapter from Point-Six, Inc. (http:///www.pointsix.com) was used to connect to a PC running Windows2000. DDE server software (also from Point Six) was developed to enable applications running under Windows to communicate with their adapter. (Note: the HA3 port adaptor has been superceded by subsequent port adaptor designs. The Maxim DS9097E port adaptor, for example, is equivalent to the earlier HA3 port adaptor.)

User control of the blinds was through a virtual instrument panel developed with National Instruments LabView 5.1 (Fig. 6), which communicated with the DDE server software. The user interface allowed for each desired motion command (tilt or raise/lower) to move one or all the blinds sequentially.

While the blind control circuitry independently operated the blinds, feedback to the user on the status of the blinds is also required. The control system was designed to return data on the slat tilt angle and whether the blinds are currently in motion. This information was transmitted over the 1-Wire network, received by the PC, and displayed on the user control panel. A quad A/D convertor chip, DS2450, also from Dallas Semiconductor/ Maxim, transmitted this data over the 1-Wire network. This integrated circuit proved to perform without deviation from its published specifications.

3.1.6. Operation

The objective of the demonstration was to check real-time operations and to identify problems that typically arise in the field (installation, wiring, electrical noise interference issues, etc.). Testing was

initiated to check operations. There were several inconsistent glitches in operations that needed fine-tuning. Two out of three Venetian blinds operated improperly due to the drag placed on the string ladders by the head rail that houses the motor. We worked with Somfy to work around this design flaw. The blinds were reinstalled and were then operated for over a year without glitches. Comments were solicited from users to improve the overall design of the interface and operations.

The IBECS network proved to reliably communicate with the blind control system. Control commands were implemented instantly. Adjustment of the pulsed power duty cycle allowed for a slow rate of tilt change that swept through the full range of tilt angle in as much as 30-45 s. This was judged to not disturb occupants in the vicinity of the blinds and proved to be quiet enough to blend in with the environmental noise level commonly found in an office setting.

3.2. *Network interface to an AC motorized shade*

Most AC tubular motor designs are appropriate for gross adjustments of a shade such as the raising and lowering of a roller shade to various pre-defined heights. The AC motor control with an IBECS interface would be similar to that designed and tested with a DC motor with the following modification. Speed control is not possible with the current type of AC motor so the complexity of multiple supply voltages (12V/24V) and pulsed power used in the DC system would be eliminated.

To use AC motors to lift and tilt Venetian blinds, the only economical, practical way to get a satisfactory rate of tilt change is to pulse the AC motor for a fraction of a second, long enough to result in a tilt change of 2-4°. To accomplish this, a solid state zero crossing AC power relay would be necessary. While more expensive than an electromechanical relay, it would be required for well controlled short power pulses. Closed-loop control could then read the tilt sensor and determine if additional tilting was necessary. Previous work with computer control of an AC powered blind used similar local power control circuitry. Experience with this blind system demonstrated that pulsed motion was noisy, augmented by the freeplay in the motor's geartrain. The resultant slat movement was undesirably jerky. For these reasons, this design was not built and tested.

Note that no changes would have been required in the AC motor IBECS interface from that used in the DC blind motor design. Modification is only needed in the power modulating, local control circuitry. If no detailed control of the AC motor is required (i.e., no tilting, only lift function required), there is no need for multiplexing the shades. Each AC motor could simply be equipped with a 2-bit digital control chip for the relay.

4. Electrochromic Window Network Interface

Electrochromic window control requires a dedicated low-voltage controller that can apply a low bipolar potential to its window. The controller must monitor current through the window and use this data to determine when the desired transmission value is reached. A satisfactory IBECS interface should be able to set a transmission value and monitor through the controller the status of window control. It is also desireable for the controller to estimate the current transmission value and be able to transmit this data through the network.

An EC controller and EC window was developed for the purpose of developing and testing an IBECS interface. The controller had an analog voltage input for transmission control and three binary status outputs. It could not output an estimate of the current window transmission. Status was outputted for "controller ready", "transmission request valid", and "window at desired transmission value". The input voltage control range was 0 to +1.4 V. The EC window measured 26 by 30 cm (10.25x12 in).

The IBECS interface used two Dallas integrated circuits: DS2890, a 100K ohms virtual potentiometer and DS2406, a two bit digital I/O IC. The former delivered an analog voltage of 0 to +1.4 V to the controller, the latter monitored two TTL logic level inputs and transmitted their state through the network. The controller had three binary outputs, but rather than add an additional DS2406, the output "controller ready" and "window at desired transmission value" were combined into an AND output. When the output is true, the controller is operating normally and the window is at a stable transmission value. Like the motorized blinds, the controller can be multiplexed to multiple EC windows.

Testing was performed by sending varied transmission requests to the controller through the IBECS interface while also monitoring the status and independently determining the transmission. Photometric

sensors were placed in front of and behind the EC window while a daylight lamp was mounted in front of the window and illuminated it. Transmission was calculated from the ratio of illuminance values from these sensors. Independent monitoring was also performed of the EC controller operation by measuring the controller's voltage that was applied to the window.

Results demonstrated excellent operation of the controller through the IBECS network. During the hours of automated operation, no erroneous transmission values were set on the controller. Status was also monitored without error. Independent measurements of the control voltage generated by the DS2890 showed that it was correct for the command sent. Controller status read through the network always correlated properly with the measurement of control voltage from the controller.

5. Discussion

The IBECS concept is compelling because costs can be reduced if control ICs typically residing on a single device can be implemented upstream in software. This is the case for 0-10 V DC controllable electronic ballasts, where real-time operations of the device are not compromised by the speed of the network. The ballast controller, which typically group controls numerous ballasts, can be replaced by the IBECS system and software upstream at a higher level. With motorized shades and electrochromic windows, however, the complex details of actuation ("change tilt angle, check, change tilt angle, check…") are best realized at the device level, downstream of the IBECS network and next to the device so as to ensure proper real-time operations. The IBECS concept is still compelling for this class of devices. Global commands can be sent through the IBECS network to actuate individual devices ("go to tilt angle 30˚") and device status can be monitored over the IBECS network. Control algorithms that integrate window and lighting systems (and their respective environmental sensors and actuators) can be implemented in software at the microLAN level.

We briefly touch on the broad topic of commissioning, maintenance and diagnostics, which is to be addressed in later work. The IBECS network system provides the flexibility to reconfigure the control layout and grouping of window systems over the life of the installation. Each IC has a globally unique address and is automatically commissioned via the 1-Wire network. However, like all networked control systems including IBECS, the physical location of each device (e.g., Building 90-3111, John Doe's office) must be input into the EMS to assign devices to user controllers and to facilitate centralized diagnostics and maintenance. Commissioning of blind motor control IC settings that relate blind motor characteristics to the tilt sensor output and the vertical height sensor output (when implemented) can be conducted via the network.

All OEM (large volume) costs were estimated, projected from our purchase price for small quantities. The OEM[5] added cost for networking is approximately $3.75 per blind. This cost will be the same for AC motors. The OEM added cost for networking and obtaining closed-loop tilt/lift control function is approximately $22 per blind (not including the cost of the blind or blind motor), where a significant percentage of this cost is due to the tilt sensor. For EC windows, the OEM added cost for networking is less than $8 per window; e.g., $1 per window with eight multiplexed EC windows. The value of the 1-Wire MicroLAN depends on its low cost compared to other control solutions. On the high end, solutions like Echelon's LonWorks provides powerful distributed control and I/O capabilities to each device at the estimated cost of $15-30 per device. On the low end, RS485 provides extremely robust and reliable control and communications capabilities and has been the standard over the past several decades. At the device level, however, RS485 requires an IC to implement control and to transmit and receive information. For individual control of fairly simple and relatively cheap devices like an electronic ballast or sensor (temperature, occupancy, etc.), RS485 is too expensive since the device-level IC can overwhelm the cost of the device itself. For individual control of more complex and expensive devices such as window systems that require device-level microprocessor-based controls capable of communicating extensive status and diagnostic information, RS485 or products like LonWorks may be more appropriate because they deliver the computational power at the device. The incremental cost reduction provided by 1-Wire also becomes a small percentage of the total cost. The benefit of the IBECS concept is therefore dependent on the particulars of the automated window system design. For non-complex window devices, IBECS can provide a low-cost solution compared to other control solutions.

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[5] Original equipment manufacturer's (OEM) cost assumes orders by the thousands.

Several key design issues need to be resolved to achieve an acceptable commercial product, but are somewhat peripheral to this discussion. The tilt sensor is a prototype sensor. This sensor does not yet meet our aesthetic criteria. It is too big and is mounted directly on one vane of the Venetian blind. The sensor relies on a chip ($5-10 OEM) that at present is purchased from a downstream vendor at a cost of $160. We expect the cost to drop to ~$10 since the same chip is used for air bags. Other solutions for determining the angle of tilt were not investigated in this scope of work. Sequential operations was also discussed earlier. If simultaneous control of multiple shades is desired, the cost for the DC motor power supply will increase. For AC motors, simultaneous operation is possible, subject to proper circuit design. Solutions that accurately control partial extension of DC motorized blinds (lining up of height between side-by-side blinds) also need to be investigated. Other practical matters for dynamic shading technologies and EC windows are discussed by industry, A/Es, and building owners in [10].

The solutions described above can be applied to all types of shading systems with some modifications to the interface between the motor and the shade ladders, tapes, or metal rungs. Vertically-hung shades tend to have no anchoring on its bottom edge so stepped tilt angle control will cause unacceptable jerky operation unless there is sufficient weight to quickly dampen out motion or the bottom edge is anchored. For heavier or more resistive slat support systems such as tapes or metal rungs, AC motors may be required to provide sufficient tilting and raising or lowering force (DC motors can be quite powerful but can be expensive due to the power supply).

6. Conclusion

By creating a functional specification for an IBECS network interface and testing the prototypes, the ability to construct such an interface was demonstrated and the cost-effective price per point better understood. Network interfaces were specified for the following devices:

- IBECS-enabled DC motorized Venetian blinds were demonstrated in an open plan. The system of three blinds were operated reliably for over two years. The interface enables one to control the tilt, raise and lower functions of a motorized blind via a 1-Wire☐ Dallas Semiconductor/ Maxim network from a virtual user LabView control panel mounted on a PC.
- An IBECS-enabled network interface to an AC-motorized shade was conceptualized. This design proved to be similar to that of the DC-motor network interface with modification needed in the power modulating, local control circuitry. This type of solution is appropriate to shades that do not require detailed control of the AC motor (e.g., no tilt, only lift function required).
- An IBECS-enabled network interface to an electrochromic (EC) window was prototyped and tested. The interface enabled one to switch the EC window to any state between clear and colored with a simple transmission command. The network interface was of similar design to the DC motor implementation and functioned reliably under a series of bench-scale tests.

With motorized Venetian blinds and electrochromic windows, the complex details of actuation ("change tilt angle, check, change tilt angle, check…") are best realized at the device level, downstream of the IBECS network and next to the device so as to ensure proper real-time operations. Global commands can be sent through the IBECS network to actuate individual devices ("go to tilt angle 30°") and device status can be monitored over the IBECS network. Control algorithms that integrate window and lighting systems (and their respective environmental sensors and actuators) can be implemented in software at the microLAN level.

The IBECS network system provides the flexibility to reconfigure the control layout and grouping of window systems over the life of the installation. Each IC has a globally unique address and is automatically commissioned via the 1-Wire network. Commissioning of blind motor or electrochromic window control IC settings can also be conducted via the network.

The OEM added cost for networking is approximately $3.75 per blind. This cost will be the same for AC motors. For EC windows, the OEM added cost for networking is less than $8 per window if a dedicated interface is assigned to each window. This cost can be reduced to $1 per window with multiplexed EC windows. OEM (large volume) costs were estimated, projected from our purchase price for small quantities.

To conclude, the IBECS concept can be appropriate for the dynamic window industry and enables one to achieve a significant cost reduction in per point networking costs. The solutions described above can be applied to all types of motorized window shading systems with some modifications to the interface

between the motor and the shade ladders, tapes, or metal rungs. Major shade and component manufacturers were informed of this research. Detailed specifications of the interface are included in this report so that manufacturers can pursue development of this networking concept if it meets their business plan. The LBNL demonstration has been showcased to numerous visitors over the past years. Further R&D is now in progress to demonstrate the higher-level integrated IBECS package that would include dimmable ballasts, photosensors, occupancy/ environmental sensors, automated shades, and switchable windows.

References

[1] Buildings Energy Databook. 2002. US Department of Energy, Office of Energy Efficiency and Renewable Energy. http://buildingsdatabook.eren.doe.gov/
[2] Building Envelope & Windows R&D meeting, Chicago, IL, December 4-6, 2002 held by the US Department of Energy, Office of Energy Efficiency and Renewable Energy's (EERE) Building Technologies Program. http://www.govforums.org/e&w/
[3] http://www.iea-shc.org/task31/
[4] Guillemin, A. and N. Morel. 2001. An innovative lighting controller integrated in a self-adaptive building control system. Energy and Buildings 33:477-487.
[5] Tenner, A.D. and L. Zonneveldt. 2002. Switchable Facades and Visual comfort. Proceedings of Right Light 5, Nice, France, May 29-31, 2002.
[6] Lee, E.S., S. Selkowitz, V. Bazjanac, V. Inkarojrit, C. Kohler. 2002. High-Performance Commercial Building Façades. LBNL-50502, Lawrence Berkeley National Laboratory, Berkeley, CA. http://gaia.lbl.gov/hpbf/
[7] http://eetd.lbl.gov/btp/buildings/cec/
[8] Rubinstein, F., P. Pettler and J. Jennings. 2002. "Dimming Every Light Cheaply". Proceedings of the *ACEEE 2002 Summer Study on Energy Efficiency in Buildings: Energy Efficiency in a Competitive Environment,* August 18-23, 2002, Asilomar, Pacific Grove, CA. Washington, D.C.: American Council for an Energy-Efficient Economy.
[9] Lee, E.S., D. L. DiBartolomeo, E.L. Vine, S.E. Selkowitz. 1998. "Integrated Performance of an Automated Venetian Blind/Electric Lighting System in a Full-Scale Private Office." *Thermal Performance of the Exterior Envelopes of Buildings VII: Conference Proceedings,* Clearwater Beach, Florida, December 7-11, 1998. http://eetd.lbl.gov/btp/papers/41443.pdf
[10] Lee, E.S., S.E. Selkowitz, M.S. Levi, S.L. Blanc, E. McConahey, M. McClintock, P. Hakkarainen, N.L. Sbar, M.P. Myser. 2002. "Active Load Management with Advanced Window Wall Systems: Research and Industry Perspectives". *Proceedings from the ACEEE 2002 Summer Study on Energy Efficiency in Buildings: Teaming for Efficiency,* August 18-23, 2002, Asilomar, Pacific Grove, CA. Washington, D.C.: American Council for an Energy-Efficient Economy. http://eetd.lbl.gov/btp/papers/50855.pdf

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